ehp

LESSON:

The Power of Cell Phones

Summary Students conduct an experiment to measure the electromagnetic emissions on various cell phones and make recommendations for reducing exposure using the inverse-square law.

Lesson Type **Experiment**—Students collect, manipulate, and/or summarize data from an experiment or activity they conduct using cell phones.

EHP Article Strong Signal for Cell Phone Effects
Environ Health Perspect 116:A422 (2008)
http://www.ehponline.org/docs/2008/116-10/forum.html#stro

Objectives By the end of this lesson, students should be able to

- collect data on electromagnetic emissions from various cell phones
- identify the parts of the electromagnetic spectrum that cell phones use
- mathematically express the relationship between power and energy
- mathematically express the inverse-square law for electromagnetic radiation
- apply the inverse-square law when making a recommendation for reducing exposure to electromagnetic radiation from cell phones

Class Time 1.5 hours

Grade Level High school, college

Subjects Addressed Biology, Environmental Science, General Science, Physical Science, Physics

Aligning with Standards

SKILLS USED OR DEVELOPED

- Classification
- Communication (written)
- Comprehension (listening, reading)
- Computation
- Critical thinking and response
- Experimentation (design, conduct, data analysis)
- Manipulation
- Observation
- Tables and figures (creating, reading)
- Technologic design
- Unit conversions

SPECIFIC CONTENT ADDRESSED

- Cell phone emissions
- Cancer
- Electromagnetic radiation
- Inverse-square law
- Power and energy
- Radio-frequency power density
- Human exposure

NATIONAL SCIENCE EDUCATION STANDARDS MET

Science Content Standards

Unifying Concepts and Processes Standard

- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement

Science as Inquiry Standard
- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Physical Science Standard
- Interactions between energy and matter

Life Science Standard
- Matter, energy, and organization in living systems

Science and Technology Standard
- Understanding about science and technology

Science in Personal and Social Perspectives Standard
- Natural and human induced hazards
- Science and technology in local, national, and global challenges

History and Nature of Science Standard
- Nature of scientific knowledge

Prepping the Lesson (15 minutes)

INSTRUCTIONS

1. Download the *EHP* article "Strong Signal for Cell Phone Effects" at http://www.ehponline.org/docs/2008/116-10/forum.html#stro.
2. Review the Background Information, Instructions, Assessing the Lesson, and Student Instructions for this lesson.
3. Make copies of the Student Instructions and the article.
4. Make an overhead transparency of the Class Data Sheet or provide a way for the students to record their cell phone data and for the class to see all of the data (such as passing around the Class Data Sheet and then making copies of the sheet for the students or group of students).
5. Gather additional materials as needed (see Materials list below and Step 2 of the Student Instructions).
6. If cell phones are restricted in your school, be sure to obtain appropriate permissions for students to use their cell phones for this activity.

MATERIALS

per student
- 1 copy of the article "Strong Signal for Cell Phone Effects"
- 1 copy of the Student Instructions
- 1 ruler with cm units
- graph paper (1-cm grid)
- cell phone (for those students who have one; alternatively, students may complete Steps 8 and 9 of the Student Instructions in groups, which would not require each student to have his/her own cell phone)

per group
- 1 electromagnetic radio frequency (RF) power meter. **The number of groups will depend on how many RF power meters you have.** These meters can be obtained from science supply catalogs and cost about $40 each (possible source: http://scientificsonline.com/). Look specifically for meters that measure cell phone frequency of 800–2,000 megahertz (MHz) as well as RF power density. The RF power meter should not be confused with a gaussmeter (also called a magnetometer), which measures magnetic fields from electric wires and components. Some RF power meters are also gaussmeters, so be sure your meter can measure RF power density. One meter can be purchased and used for the entire class if funds are limited.
- graph paper (1-cm grid)
- 1 flashlight
- 1 ruler with cm units
- 2 cell phones
- stopwatch or watch with a second hand

per class
- Overhead transparency of the Class Data Sheet

VOCABULARY

- electromagnetic spectrum
- energy
- exposure
- inverse-square law
- ionizing
- joules (J)
- non-ionizing
- power
- power (surface) density
- radio frequency
- radio-frequency power meter
- radio-frequency power (surface) density
- surface area
- volume
- watts (W)

BACKGROUND INFORMATION

In this lesson students measure the power density of radio-frequency (RF) electromagnetic emissions from various cell phones (electromagnetic power density is measured in units of power per unit area and is sometimes called "power surface density"). Once they learn about the electromagnetic spectrum and the inverse-square law, they design their own experiment to test their hypotheses about reduction of power density as a function of distance from the source of the radiation (and by extension how cell phone placement may affect exposure to radiation and, subsequently, health).

The lesson focuses on three main physics concepts: a) the electromagnetic radiation (EMR) spectrum; b) power and energy as they apply to cell phone emissions; and c) the inverse-square law. The lesson also focuses on the power density of RF EMR. The concepts of electromagnetic fields and specific absorption rate (SAR) limits are not explicitly addressed in the student activity but are important background information and are discussed below to assist you.

Electromagnetic Fields

An electromagnetic field is formed by charged particles such as electrons and protons. If the particles are s*tationary* with respect to an observer, they will produce an electric field with no magnetic component. If the particles are *moving* with respect to an observer, they will produce a magnetic field. When particles change their motion, the associated electromagnetic field changes, producing EMR (which includes gamma and X rays, visible light, and radio waves). The electromagnetic signals that carry information between cell phones (or between any devices that can transmit and/or receive EMR) are produced by the change in motion of electrons (negatively charged particles) as they oscillate back and forth within the metal wires that make up the antenna inside the cell phone. The energy of EMR depends on its frequency; high-frequency EMR, such as gamma rays and X rays, is very energetic (on the order of 2×10^{-14} J), whereas low-frequency EMR, such as microwave and radio emissions, is much less energetic (around 2×10^{-22} J). Refer to Figure 1 in the Student Instructions for additional information on the relationship between energy, frequency, and wavelength in the electromagnetic spectrum.

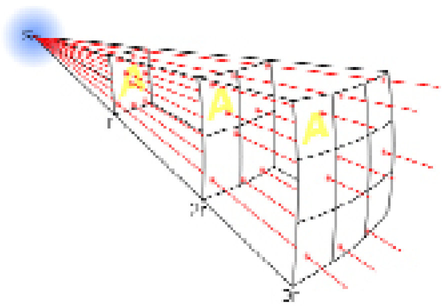
When referring to biologic radiation exposures, EMR is divided into two types of radiation—ionizing and non-ionizing. Because the human body is composed of about 60% water, *ionizing* and *non-ionizing* refer to whether the RF energy is high enough to break chemical bonds of water (ionizing) or not (non-ionizing). Technically, ionizing radiation is the amount of energy that can remove an electron from a water molecule (1,216 kJ/mol), and non-ionizing radiation is anything less than that amount.

Because radio and microwave radiation are non-ionizing, many researchers originally hypothesized that exposure to the radio emissions from cell phones would likely not cause health problems (although we know from our everyday experience of heating a bowl of soup in the microwave oven that microwave radiation can affect water significantly). Even so, as a precautionary measure, the U.S. Federal Communications Commission (FCC) and the European Union have placed limits on the frequencies and total power used by cell phones; these are known as SAR (specific absorption rate) limits and reflect how much RF energy is absorbed by the body when using a cell phone. The FCC has set the SAR limit for public exposure to RF energy from cell phones at 1.6 watts per kilogram of body tissue (1.6 W/kg). The European Union SAR limit is 2 W/kg, averaged over 10 grams of tissue. The average adult brain weighs about 1.5 kg, so the maximum exposure from cell phones should be about 2.5–3.0 W. Most cell phone manufacturers limit the total power of their cell phones to less than 1 W.

SAR Limit

For this lesson, we are interested in how much energy is received at a location (the brain) from a transmitting source (the cell phone), which is usually measured as the energy received per second over a specific area. We call this measurement "power density," measured in units of watts per square meter (W/m^2) or milliwatts per square centimeter (mW/cm^2). These units are used to evaluate the intensity of exposure to the ear and the brain. Because EMR propagates away from the source in all directions, the power intercepted by a fixed surface area decreases as the distance between it and the source increases.

For cell phones, the distance between the emission source (the antenna in the cell phone) and the intercepting surface (usually the human head) is very small, as cell phones are typically held against the ear. Therefore, holding the cell phone next to the ear transmits the maximum EMR power to the head of the cell phone user. Just as a microwave oven can heat and cook meat, the power from a closely held cell phone may affect brain tissue if the head is exposed to the cell phone radiation for extended periods



The image at left shows a that a given surface, *A*, at the distance *r*, is being hit by energy (red lines) radiating from the source *S*. As *A* moves farther away from the source, less energy (fewer red lines) hits the same surface area (represented by the square labeled “A”).

of time.

Source: Wikipedia Commons (http://en.wikipedia.org/wiki/Image:Inverse_square_law.svg).

The FCC developed the SAR to quantify this exposure and its potential effects. The SAR values for specific cell phones can be found on websites—including SAR Values at http://www.sarvalues.com/usa-highest-sar.html (which provides a list of cell phones with the highest and lowest SARs) and the Mobile Manufacturers Forum at http://www.mmfai.org/public/sar.cfm?lang=eng—or through searching the Internet using the terms “SAR” and “cell phone.” Currently, the primary source for SAR data is from the phone manufacturers themselves.

As mentioned in the *EHP* article “Strong Signal for Cell Phone Effects,” one complication in assessing the effects of cell phone use on humans is the duration of the exposure. The SAR values reflect continuous exposure, but many cell phones emit radiation in short bursts, and as with the food in your microwave, the duration of the exposure may be important. As research continues in this area, investigators will need to tease out various exposure variables, such as the risk from short-term exposure to higher radiation bursts versus long-term exposures to the phone radiation (this can vary depending on the type of phone).

The SAR limit is not explicitly discussed in this lesson because the goal of this lesson is to have students identify a way to reduce exposure, which is a function of the inverse-square law (i.e., it reintroduces the distance variable).

RESOURCES

Environmental Health Perspectives, Environews by Topic page, http://ehp.niehs.nih.gov/. Choose Radiation/Radioactivity, Telecommunications/ Information Technology

Federal Communications Commission. Cellular Telephone Specific Absorption Rate. http://www.fcc.gov/cgb/sar/

Federal Communications Commission. Radio Frequency Safety. http://www.fcc.gov/oet/rfsafety/rf-faqs.html

How Stuff Works. How Cell Phones Work. http://electronics.howstuffworks.com/cell-phone1.htm

World Health Organization. International Electromagnetic Fields Project. http://www.who.int/peh-emf/en/

Implementing the Lesson

INSTRUCTIONS

1. Distribute copies of the *EHP* article “Strong Signal for Cell Phones Effects” and the Student Instructions. Have students read the article individually or as a class. Address any questions or clarify terminology as needed.
2. Review Step 2 of the Student Instructions with the class. Divide the students into groups depending on the number of RF meters you have. Some meters have different sensitivity settings (also called “scale”). If students have difficulty locating a signal on their meters, they may need to place the meters on the highest sensitivity setting. Conversely, if a signal continuously goes “off the scale” the lower sensitivity setting should be used. Distribute graph paper, then have students complete Step 2.
3. Have students individually complete Steps 3 and 4 of the Student Instructions. Review the concepts of *electromagnetic*

spectrum, *energy*, *power*, and *wavelength* with the class as needed before beginning Step 5.

4. Distribute flashlights to the groups of students, then review the instructions for Step 5. Have the students complete Step 5.
5. Have students individually complete Steps 6, 7, and 10. Steps 8 and 9 can be completed individually or in groups, depending on the number of available RF meters and your teaching preference. Students can write their experimental protocol individually, share their protocols within small groups, then combine and/or modify protocols to create a well-constructed group protocol, which would then be implemented.
6. As a class, discuss student recommendations made in Step 10.

Notes & Helpful Hints

- An extension of this activity could be to test cell phone radiation shield products that claim to reduce the amount of EMR that enters a user's head.

Assessing the Lesson (steps not requiring teacher feedback are not listed below; see Student Instructions for complete step-by-step instructions)

Step 2 **a.–g. Now divide into groups as instructed by your teacher, and complete the following data collection activity with your assigned group.**

Students should record five readings and calculate the average of those readings. They should note whether the signal consistently exceeded the range of the meter.

h. Was the RF signal steady or did it drop out frequently (intermittent)? Describe.

Students should describe how steady the signal was from the phone.

i. Record the following data for your phone onto the Class Data Sheet.

Data should be correctly transferred to the Class Data Sheet.

Step 3 **a. Refer to the completed Class Data Sheet and rank the cell phone manufacturers and models from highest to lowest RF power density in the table below. If multiple cell phones "tied" for a certain ranking, number each of the tied phones the same (for instance, if two phones tied for the highest rank, label both phones "1"). Label the table fields as needed.**

Answers will vary based on the number and types of cell phones present in the class. Make sure these data are consistent with the highest and lowest RF power density for the class.

b. Is there a lot or a little variability in the RF power density between the different types of cell phones? Explain why or why not.

Answers will vary depending on the types of cell phones present in the class and whether the phones have steady or intermittent signals. Students may also differ in their assessment of variability; look for logical responses. For example, one student may argue that it's impossible to know the variability without a larger sample size or that the concept of "a little" or "a lot" requires a better understanding of the range and/or accuracy of the measurement or measuring device. Another may state that there is a lot of variability because different phones measured on the low end of the meter, the middle of the meter, and the high end of the meter.

Step 4 **a. Cell phones use a specific frequency range, 800–2,000 megahertz (MHz), of the electromagnetic spectrum. Refer to Figure 1 below, then list the common names of the parts of the electromagnetic spectrum that cell phones use.**

Radio/TV and microwave

b. What happens to the energy as you move from radio waves to gamma rays?

The energy increases as you move from radio waves to gamma radiation.

c. **Power is the amount of energy per amount of time and is expressed in units of watts (W). Energy is measured in units of joules (J), and time is measured in units of seconds (sec). Write the equation for power two ways: 1) using the words *power*, *energy*, and *time* and 2) using abbreviations for watts, joules, and seconds.**

1) power = energy/time
2) W = J/sec

d. **Refer to the equations you wrote in Step 4c. What happens to the power as the energy increases? Does this match your understanding of the relationship between power and energy? Why or why not? Provide a "real world" example.**

The power increases as the energy increases. A real-world example students may be familiar with is a light bulb—the higher the wattage, the more energy is used.

Step 6 **One of the important laws in physics is the inverse-square law. The inverse-square law states that the intensity (I) or power density of light (or any other form of electromagnetic radiation) is inversely proportional to the square of the distance (r = radius) from the energy source (original power, P_o). Write the equation for the inverse-square law two different ways: 1) using the words *intensity*, *original power*, and *distance squared* and 2) using the symbols I, P_o, and r.**

1) intensity = (original power)/(radius distance squared)
2) $I = P_o/r^2$

Step 7 **If you were to remeasure the RF power density of a cell phone at different distances from the listening end of the phone, what do you hypothesize would happen at various distances? Write your hypothesis below and include the inverse-square law.**

Students should have a clearly written hypothesis that references the inverse-square law and includes a statement of how they think RF power density will change as a function of distance.

Step 8 **Write a protocol for an experiment to test the hypothesis you developed in Step 7. Be very specific (for instance, include specific distances you will need to measure, describe where to take the measurements in relation to the location of the phone and the meter, etc.). Use an additional piece of paper if you need extra space.**

Students should provide a clear step-by-step protocol that tests their hypothesis. Well-designed protocols will include the following elements.

- Describe where to take the measurements in relation to the location of the phone and the meter.
- Describe the measurement distances from the phone. Make sure the distances are logical. For example, measuring in millimeter increments may not work because the instrument probe size may be too large for such small distances. You also want to make sure there are enough measurements for students to demonstrate a change in emission over distance and, if possible, demonstrate the inverse-square law. Two measurements are probably insufficient.
- Describe the tools/instruments needed to conduct the experiment and how those tools will be used.
- Have a data sheet, notebook, etc., on which to record data .
- Students should ideally build repetitions (e.g., a minimum of three repetitions) into the protocol and average the data.
- To understand absorption, students could put barriers (such as paper, aluminum, or lead-filled X-ray protection barriers) between the source and the receptor.

Step 9 a. **Did your results support or not support your hypothesis? Explain and use data to support your answer. b. What are some possible sources of error? How could you minimize their impact? c. How could you modify your experiment to improve it? Explain the modifications and why they would improve the design or the resulting data.**

Look for clear, logical, well-supported answers. Students should provide enough data to support their conclusions, and there should be a match between the data and conclusions. Students also need to describe how they could improve their experiment. If they wrote their own individual protocols and then worked as a group to create a group protocol, they can discuss any changes they made. Students should describe how a specific change would improve the research design and affect the resulting data. For example, if they wanted to use a different instrument they would need to consider the following: What would the instrument measure? Why would they choose that particular instrument? How could the instrument potentially change the data (e.g., a different type of measurement, increased accuracy?

Step 10 **Based on your experiment, what recommendations would you give to your friends who talk frequently on their cell phones? Explain and use your data to support your explanation.**

Students should provide a specific and clear explanation. They may use examples/suggestions from the article, but they need to explain why they chose those suggestions in the context of their data. The more specific the recommendations the better—for example, use an earpiece with a cord of x length, use speaker phone at x distance, use a Bluetooth or other headset (which does emit electromagnetic radiation but much less than the cell phone alone), use text messaging, etc.

Authors and Reviewers

Authors: Stefani Hines, the University of New Mexico College of Pharmacy; Dean C. Hines, Space Science Institute

Reviewers: Jennifer K. Campbell, Laura Hemminger, and Paul Lioy, University of Medicine & Dentistry of New Jersey; Philip M. Iannaccone, Northwestern University; Susan M. Booker, Martha M. Dimes, Erin Dooley, and Dorothy L. Ritter, *Environmental Health Perspectives*

Give us your feedback! Send comments about this lesson to ehpscienceed@niehs.nih.gov.

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The Power of Cell Phones

Step 1 Read the article "Strong Signal for Cell Phone Effects."

Step 2 You will be using a radio frequency (RF) power meter, a measuring device that detects RF power density, to test radio frequency emissions from cell phones. NOTE: If you have specific questions about how to operate the meter, refer to the instructions enclosed with the meter.

After conducting the experiment, you will learn more about RF radiation and how that relates to the electromagnetic spectrum (energy), as well as power density and how basic physics laws could be applied to protect human health.

Now divide into groups as instructed by your teacher, and complete the following data collection activity with your assigned group.

a. Decide which two group members' cell phones or devices with a cell phone (e.g., PDA, iPhone, Blackberry) you will use for the activity. (Your teacher will obtain appropriate permissions for you to use your cell phone for this activity if cell phones are restricted in your class or school.) Decide which phone will be Cell Phone #1 and which will be Cell Phone #2.

b. When instructed by your teacher, turn on the cell phones.

c. Place a piece of graph paper on the table. Put the RF meter or sensor probe on the piece of graph paper. Put Cell Phone #1 on the paper 5 cm from the meter or sensor probe (if you are using 1-cm graph paper, the distance between the probe and the cell phone would be 5 squares). NOTE: Be sure not to place the sensor immediately next to the phone, and keep the sensor and phone stationary because moving the devices can cause errors in the readings.

d. Use Cell Phone #2 to call Cell Phone #1. If Cell Phone #1 is a flip phone, you should have the phone open and press the "answer" button to accept the call.

e. Orient Cell Phone #1 around the meter so that it gives the strongest signal (the highest RF in milliwatts per square centimeter, mW/cm^2) at the 5-cm distance. Once you find the strongest signal, keep Cell Phone #1 on the table in the same position by the meter at all times.

   Some phones emit signals in bursts, so it may require several calls to find the strongest signal. You may have to adjust the sensitivity of the RF meter (by adjusting a switch on the meter) so the signal can be measured. A weak signal may require a higher sensitivity setting than a strong signal. Once you find the strongest signal, take five readings by initiating five 30-second calls. When calling and talking on the phone, hold the phone stationary and at a consistent distance of 5 cm from the RF meter or sensor probe.

f. Record the five RF readings in the table below and calculate the average.

	Cell Phone #1	Cell Phone #2
Reading 1		
Reading 2		
Reading 3		
Reading 4		
Reading 5		
Average (mW/cm^2)		

g. Repeat the steps for Cell Phone #2, recording the five RF readings and averaging the results in the table above.

h. Was the RF signal steady or did it drop out frequently (intermittent)? Describe.

i. Record the following data for your phones onto the Class Data Sheet.

- The phone manufacturer and model (this information should be found on the phone; you may need to look inside the battery area)
- The average RF power (surface) density in mW/cm^2
- Whether the signal was steady or intermittent

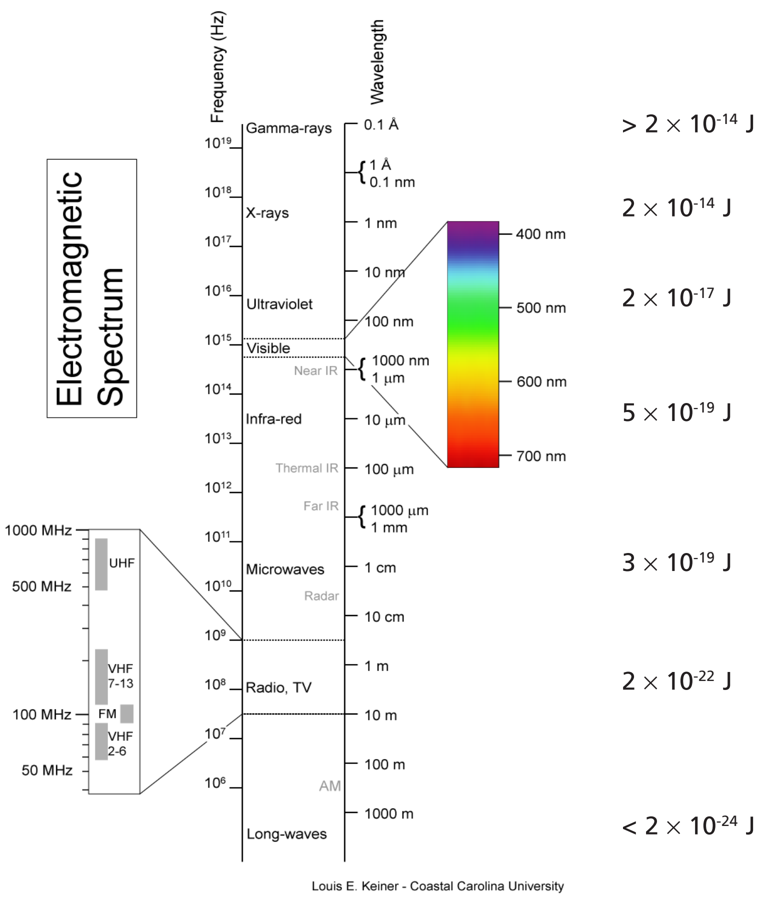
Step 3 a. Refer to the completed Class Data Sheet and rank the cell phone manufacturers and models from highest to lowest RF power density in the table below. If multiple cell phones tied for a certain ranking, number each of the tied phones the same (for instance, if two phones tied for the highest rank, label both phones "1"). Label the table fields as needed.

Rank (Highest to Lowest)	Cell Phone Manufacturer	Cell Phone Model	RF Power Density (mW/cm^2)	Steady or Intermittent Signal

b. Is there a lot or a little variability in the RF power density between the different types of cell phones? Explain why or why not.

Step 4 a. Cell phones use a specific range of the electromagnetic spectrum [800–2,000 megahertz (MHz)]. Refer to Figure 1 below, then list the common names of the parts of the electromagnetic spectrum that cell phones use.

Figure 1: The Electromagnetic Spectrum



b. What happens to the energy as you move from radio waves to gamma rays?

c. Power is the amount of energy per amount of time and is expressed in units of watts (W). Energy is measured in units of joules (J), and time is measured in units of seconds (sec). Write the equation for power in two ways: 1) using the words *power*, *energy*, and *time* and 2) using abbreviations for watts, joules, and seconds.

1)

2)

d. Refer to the equations you wrote in Step 4c. What happens to the power as the energy increases? Does this match your understanding of the relationship between power and energy? Why or why not? Provide a "real world" example.

Step 5 In general, density refers to the amount (usually in the units of mass) of a substance per volume. However, when referring to electromagnetic radiation, surface area is used instead of volume. This is why the RF power (surface) density you are measuring is measured as mW/cm^2.

The following activity will illustrate this point.

a. Your teacher will distribute flashlights.

b. Using the graph paper from the activity in Step 2, color in one square of the graph paper in the middle of the paper.

c. Hold the flashlight 5 cm from the paper and center the beam on the colored square. Observe the intensity of the light.

d. Move the flashlight to a distance of 10 cm from the paper and observe the intensity of the light.

e. You should notice the spot size of the light increase and the intensity of the light decrease. Although the total power coming from the flashlight is the same, the power that hits one part of the surface (i.e., the power per unit area or power density) decreases as the distance increases.

Step 6 One of the important laws in physics is the inverse-square law. The inverse-square law states the intensity (I) or power density of light (or any other form of electromagnetic radiation) is inversely proportional to the square of the distance (r = radius) from the energy source (original power, P_o). Write the equation for the inverse-square law two different ways: 1) using the words *intensity*, *original power*, and *distance squared* and 2) using the symbols I, P_o, and r.

1)

2)

Step 7 If you were to remeasure the radio frequency (RF) power (surface) density of a cell phone at different distances from the listening end of the phone, what do you hypothesize would happen at various distances? Write your hypothesis below and include the inverse-square law.

Step 8 Write a protocol for an experiment to test the hypothesis you developed in Step 7. Be very specific (for instance, include specific distances you will need to measure, describe where to take the measurements in relation to the location of the phone and the meter, etc.). Use an additional piece of paper if you need extra space.

NOTE: Use a phone with a continuous signal (such as phones with Wi-Fi/Internet access, which are continuously "active" as they seek a Wi-Fi connection).

Step 9 Conduct your experiment and record your data and conclusions below. Use additional paper if you need extra space.

a. Did your results support or not support your hypothesis? Explain and use data to support your answer.

b. What are some possible sources of error? How could you minimize their impact?

c. How could you modify your experiment to improve it? Explain the modifications and why they would improve the design or the resulting data.

Step 10 Based on your experiment, what recommendations would you give to your friends who talk frequently on their cell phones? Explain and use your data to support your explanation.

Class Data Sheet

Cell Phone Manufacturer	Cell Phone Model	Average RF Power Density (mW/cm^2)	Steady or Intermittent Signal